In the extreme right-hand column of this table, where 1 denotes a single unit, the figures 1, **1**, 0 are written each once and then repeated in the same order, and so on to the end. In the second column, where 1 denotes three units, each figure is repeated three times, and then again three times, and so on to the end, but this column begins at the value $\frac{3+1}{2}$. The third column, where 1 denotes nine units, begins at the value $\frac{9+1}{2}$, and the figures are repeated nine times. The fourth column, in which 1 stands for 27, begins at the value $\frac{27+1}{2}$, and contains only the figure 1, twenty-seven times repeated. Hence it will be found that, in order to weigh all the pounds from one to forty, we shall have to make use of *each* weight twenty-seven times.

If, instead of four, seven weights were used, we might, by using each weight $3^6 = 729$ times, weigh any number of pounds from 1 to $729 + \frac{729-1}{2} = 1093$[1] pounds.

Further, we may, for any given number of weights, construct tables, one for each weight, showing the numbers of pounds for which it will be used positively, and also indicating by different type the numbers for which it has to be subtracted. Thus, with five weights we should have for the first four the following tables, whilst the fifth would contain the 81 consecutive numbers beginning with 41 and ending with 121, all to be used positively.

1	4	7	10	13	16	19	22	25
28	31	34	37	40	43	46	49	52
55	58	61	64	67	70	73	76	79
82	85	88	91	94	97	100	103	106
109	112	115	118	121	**2**	**5**	**8**	**11**
14	**17**	**20**	**23**	**26**	**29**	**32**	**35**	**38**
41	**44**	**47**	**50**	**53**	**56**	**59**	**62**	**65**
68	**71**	**74**	**77**	**80**	**83**	**86**	**89**	**92**
95	**98**	**101**	**104**	**107**	**110**	**113**	**116**	**119**

2	3	4	11	12	13	20	21	22
29	30	31	38	39	40	47	48	49
56	57	58	65	66	67	74	75	76
83	84	85	92	93	94	101	102	103
110	111	112	119	120	121	**5**	**6**	**7**
14	**15**	**16**	**23**	**24**	**25**	**32**	**33**	**34**
41	**42**	**43**	**50**	**51**	**52**	**59**	**60**	**61**
68	**69**	**70**	**77**	**78**	**79**	**86**	**87**	**88**
95	**96**	**97**	**104**	**105**	**106**	**113**	**114**	**115**

5	6	7	8	9	10	11	12	13
32	33	34	35	36	37	38	39	40
59	60	61	62	63	64	65	66	67
86	87	88	89	90	91	92	93	94
113	114	115	116	117	118	119	120	121
14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**
68	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**
95	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**

14	15	16	17	18	19	20	21	22
23	24	25	26	27	28	29	30	31
32	33	34	35	26	37	38	39	40
95	96	97	98	99	100	101	102	103
104	105	106	107	108	109	110	111	112
113	114	115	116	117	118	119	120	121
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**
50	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**
59	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**

Supposing, now, we wished to determine how any number of pounds, less than 122, may be weighed by means of the weights 1, 3, 9, 27, 81, we seek the number in question, say, for example, 115, first in the upper part of each of the first four tables, as well as in the fifth, and find in this way that we shall require to place all the weights except the weight 3 on one side of the balance; and as the same number is found in thick type in the second table, we see that the weight 3 must be placed in the opposite scale of the balance, and we have $1 + 9 + 27 + 81 - 3 = 115$. In like manner $70 = 1 + 81 - (3 + 9)$ and $38 = 3 + 9 + 27 - 1$. It is manifest that these tables, like the similar tables founded on the binary series, 1, 2, 4, &c., may be used to discover what number up to a certain limit a person has thought of, on being informed first in which of the tables the number occurs in the upper part of the table, and then in which, if any, of the remaining tables it is found in the lower part. For this purpose it is only necessary to add together, not the lowest numbers at the head of the tables, as for the binary series, but to take in each table a number one less than the double of the lowest number, both in the positive and in the negative group, and then to subtract the second sum from the first.

Many facts respecting such tables as the above may be ascertained from the following rows of numbers, which are formed, a column at a time, beginning on the left with 1, 0, 1, and adding the last number to each of the former two, which gives 2, 1 and their sum, 3, for the second column; from these 3 + 2, 3 + 1, and their sum, for the third, and so on.

1 .	2 .	5 .	14 .	41 .	122 .	365 .	1094
0 .	1 .	4 .	13 .	40 .	121 .	364 .	1093
1 .	3 .	9 .	27 .	81 .	243 .	729 .	2187

The upper row contains the lowest numbers in the several tables; the middle number in any column shows the highest number of units that can be weighed with the weights shown in the last row as far as the preceding column. The first two rows, moreover, show, in reverse order, how many times each weight will be used positively or negatively. The *highest* of the weights, for example, will be used only positively, as shown by the numbers 1, 0 in the *first* column, the weight next to the highest will be used twice as often positively as negatively, as shown by the numbers 2, 1 in the *second* column, and so on. Thus, for five weights we should have in the *first* table, as shown by the *fifth* column, 41 numbers in the upper part of the table, 40 in the lower part; in the second table the corresponding numbers are 3 × 14 and 3 × 13; in the third 9 × 5 and 9 × 4, and in the fourth 2 × 27 and 27, as we have already found above.

J. WILLIS.

Bradford, October 22.

THE CELL THEORY, PAST AND PRESENT.[1]

II.

THE continued investigations into the structure of cells, both in plants and animals, led to modifications in the conception of their morphology. Hugo von Mohl announced that he had discovered (*Botanische Zeitung*, translated by A. Henfrey in Taylor's "Scientific Memoirs," vol. iv., 1846) in the vegetable cell, after being acted on by alcohol and iodine, a thin nitrogenous membrane distinct from and applied to the inner surface of the cellulose wall of the cell, which he named the *primordial utricle.* He regarded it as forming a vesicle within the cell wall, and containing the contents and the nucleus. By subsequent observers it has been shown that the primordial utricle is nothing more than a thin layer of protoplasm lying close to the cellulose wall, and inclosing the sap cavity of the cell.

Prof. Huxley, in an article on the cell theory (*British and Foreign Medico-Chirurgical Review*, October 1853), criticized the views of Schleiden and Schwann, and introduced the terms *endoplast* and *periplast* into histological description. He regarded the primordial utricle as the essential part of the endoplast in the plant, and as homologous with the "nucleus" of the animal cell; whilst the protoplasm and nucleus are simply its subordinate modifications. The periplast, on the other hand, consisted in plants of the cellulose cell wall; whilst in animals the cell wall and matrix of cartilage, the cell walls and intercellular substance of connective tissue, the calcified matrix of bone, and the sarcous elements of muscular fibre, were all examples of periplast which had passed through various forms of chemical and morphological differentiation. Huxley maintained that the periplast was the metamorphic element of the tissues, and by its differentiation every variety of tissue was produced, owing to intimate molecular changes in its own substance. The endoplast again might grow and divide, as in the process of cell multiplication; but it frequently disappeared, and underwent neither chemical nor morphological metamorphosis; and so far from being a centre of vital activity, he held that it exercised no attractive, metamorphic, or metabolic force upon the periplast.

---

[1] The coincidence of this number with the number of NATURE in which this subject was introduced is, of course, purely fortuitous.

[1] The Inaugural Address delivered to the Scottish Microscopical Society, by Sir William Turner, F.R.SS. L. and E., President of the Society. Continued from p. 15.

But about this time it began to be more distinctly recognized that many anatomical units which were to be regarded as cells, as Schwann had indeed admitted in a few exceptional cases, possessed no cell wall or investing membrane, and that the analogy with a bladder or vesicle could no longer be sustained. Thus in 1856 ("Lehrbuch der Histologie," 1857; preface dated October 1856), Leydig gave as his idea of a cell a more or less soft substance, approaching in its original state to the globular in form, which inclosed a central body, the nucleus. Subsequently, the cell substance might harden into a more or less independent membrane, and the cell would then consist of membrane, contents, and nucleus. Leydig's conception, therefore, of what were the essential parts of a cell closely corresponded with the opinion expressed some years previously by John Simon. Brücke again maintained ("Elementarorganismen," *Wien. Sitzbericht*, 1861) that the constancy of the presence of a nucleus was subject to certain limitations, especially in the cells of cryptogams, and that there was no positive information either respecting the origin or the function of the nucleus. He further showed that the soft contents of the cell were of a highly complicated nature, and that they frequently exhibited spontaneous movements and contractility. In 1861 and also in 1863, Max Schultze published (*Müller's Archiv*, 1861, p. 1; "Das Protoplasma," Leipzig 1863), most important papers on the properties of cells. He adopted the term protoplasm which Von Mohl had employed to designate the contents in vegetable cells which surround the nucleus, and applied it to the substance which had the corresponding position in animal cells. He completely discarded the view that a membrane was essential to a cell, and defined a cell as a nucleated mass of protoplasm. He identified the protoplasm of the animal and vegetable cell as essentially the same substance as the contractile sarcode which forms the freely moving pseudopodia of the Rhizopoda, and he looked upon it as possessing great physiological activity. The conception of the functions and relative importance of the constituent parts of a cell had now undergone a material change. The suggestive ideas of Simon and Leydig had been distinctly formulated by Max Schultze. Instead of the cell membrane being regarded as a necessary part of a cell, and the active element concerned in the formation of the cell contents, as Schwann believed, it now became universally recognized as only a secondary structure formed by a differentiation of the superficial part of the protoplasm. Schultze also maintained that the appearance of the membrane might be looked upon as a sign of commencing loss of activity, for a cell with a membrane can no longer divide as a whole, but the division is restricted to the protoplasm contained within it. A cell with a membrane is, he says, like an encysted Infusorian. Taking the embryonal cell as a type, he believed that both the nucleus and the protoplasm were derived from the corresponding constituents of another cell. The protoplasm was the substance especially endowed with living force; the nucleus, he thought, played an important *rôle*, though its exact function could not be defined. The only structural character which Schultze recognized in the protoplasm was a finely granular appearance throughout the somewhat jelly-like, contractile material in which the granules were embedded. Although the name of protoplasm was now given to this substance, yet it obviously corresponded morphologically with the blastema which both Schleiden and Schwann had recognized within the cell, between the nucleus and the cell wall; though it now assumed in the minds of observers a different physiological import.

The reign of protoplasm had now been inaugurated. Not only was the cell membrane believed to be a product of its differentiation, but the matrix of cartilage and of connective tissues, and the other intercellular substances, were thought to be produced not as a secretion, but by a conversion of the protoplasm of the cells into their respective forms. But, further, Max Schultze ("Organis. der Polythalamien," 1854) described a non-nucleated Amœba; and Haeckel (*Zeitsch. f. wiss. Zool.*, 1865, Bd. xv.) and Cienkowski (Max Schultze, *Archiv*, 1865) other non-nucleated organisms, simple in their structure. These organisms were believed to consist solely of a clump of soft protoplasm, which might either be naked, when they were called *simple cytodes;* or encased in a wall or envelope, and then termed *encased cytodes.* Haeckel named these—the most simple of all organisms—Monera, and referred them to a group on the confines of both the animal and the vegetable kingdoms, which he termed Protistæ. Stricker ("Allgemeines über die Zelle," in "Handbuch der Lehre von den Geweben," Leipzig, 1871) also excluded the nucleus as necessary to our conception of an elementary organism. He went so far as to say that the historic name of cell might be applied to the morphological elements of the higher animals, or to independent living organisms, even if they were only little masses of animal sarcode or protoplasm. He was not, however, disposed to extend the definition to isolated fragments of living protoplasm, unless the whole group of phenomena characteristic of an independent organism could be recognized. Stricker held that protoplasm may be fluid, solid, or gelatinous. It exhibited the phenomena of movement, of nutrition, of growth, and the capability of reproducing its like, *i.e.* the sum of the phenomena which are characteristic of living organisms.

The doctrine that a nucleated mass of protoplasm was the structural unit common to organisms generally, both plants and animals—though at the very bottom of the scale the phenomena of life could be manifested by a particle of protoplasm without a nucleus—received its most popular expression, in this country at least, in a well-known address by Prof. Huxley.[1] In this address he stated that protoplasm, simple or nucleated, is the formal basis of all life, and that all living forms are fundamentally of one character. His views, therefore, had undergone some modification, as to the element of the tissue in which vital activity was more especially centred, since the publication of his previous article on the cell theory.

But contemporaneous with these researches on the protoplasmic theory of cell structure and activity, an English physiologist, Dr. Lionel Beale, was conducting investigations into the structure of the simple tissues from an independent and somewhat different point of view. He considered that the elementary tissues of every living being consisted of matter in two states ("Structure of the Simple Tissues," London, 1861)—the one an active, living, growing substance, composed of spherical particles, capable of multiplying itself, and coloured red by carmine, which he named *germinal matter;* the other, named by him *formed material*, was situated peripherally to the germinal matter from which it was produced; it was passive, non-living or dead, incapable of multiplying itself, and not coloured red by carmine like the germinal matter. In adapting these terms to the ordinary nomenclature of the cell, Dr. Beale states:—

> "In some cases the germinal matter corresponds to the 'nucleus'; in others, to the 'nucleus and cell contents'; in others, to the matter lying between the 'cell wall,' and certain of the 'cell contents'; while the formed material in some cases corresponds exactly to the 'cell wall' only; in others, to the 'cell wall and part of the cell contents'; in others, to the 'intercellular substance'; and, in other instances, to the fluid or viscid material which separates the several 'cells, nuclei, or corpuscles' from eachother."

According to this theory of the tissues, all the elementary parts of the body consist of two substances—an active, living, germinal matter, an inactive, non-living, formed material. Every living elementary part is derived from a pre-existing living elementary particle. The nuclei of the germinal matter, though remaining for a long time, perhaps, in a comparatively quiescent state, may become active and give rise to new nuclei. Dr. Beale held that the cell wall was by no means constantly present in cells, and that, when present, both it and the intercellular substance were formed or produced by, or a conversion of, the germinal matter. In a subsequent work, Beale ("Bioplasm," London, 1872) substituted the term *bioplasm* for germinal matter, and included in it the nucleus, nucleolus, and some forms of protoplasm. It is, he says, from the bioplasm that the formed material is produced.

---

[1] "On the Physical Basis of Life," a Lay Sermon delivered November 8 1868, *Fortnightly Review;* also in "Lay Sermons and Addresses," London 1870.

An important advance was made in the conception of the structure of the constituent parts of the cell when it was ascertained that protoplasm was not the structureless, granulated jelly, or slime, which it was originally supposed to be, but that it consisted of two parts, viz. a minute network of very delicate fibrils and an apparently homogeneous substance which occupied the interstices of the network. Stilling and Max Schultze recognized the fibrillated character of the protoplasm of nerve cells and axial cylinders, but Frommann, Heitzmann, Klein, and other histologists applied the observations to the structure of protoplasm generally.

The subject made yet a greater step forwards when it was ascertained by Strasburger and Flemming that the nucleus in its passive or resting stage consists, in addition to the nucleolus, of threads or fibres, some finer, others coarser, formed of *nuclein*, and arranged in a reticular network, so as to form little knots at the points of intersection of the fibres. In the interstices of the network an apparently structureless intermediate substance, nuclear fluid or *nucleoplasm*, is situated; and the nucleus is surrounded by a membrane.[1] By some observers the threads are regarded not as forming a network, but as a greatly coiled single thread. From the affinity which they have for colouring-matter, so that they easily stain with dye, Flemming has named them *chromatin fibres*.[2] But the whole question of the relation of the nucleus to the life of the cell, more especially in connection with the production of young cells, assumed a much more definite form when it was discovered that the chromatin nuclear fibres took a primary part in the division of the nucleus in the process of cell multiplication. The nucleus was now reinstated in its place as of primary importance in the structure of cells, and as an essential factor in the formation of new cells. The movements of the fibres within the nucleus, and their rearrangement so as to form definite figures, which changes precede the act of division, were named by Schleicher *karyokinesis*,[3] or nuclear movement, a term which has now been generally adopted.

Waldeyer states that Schneider, of Breslau, was the first to recognize these movements of the nuclear fibres, and to describe them in connection with the division of the ova, the sperm cells, and also the tissue cells of a flat worm, *Mesostomum*; but Bütschli and Foli made the process more generally known. The publication of their researches excited the greatest interest, and a host of observers, amongst whom I may especially name Strasburger, Flemming, Hertwig, Balbiani, E. van Beneden, Johow, Heuser, Pfitzner, J. M. Macfarlane, Carnoy, and Rabl, demonstrated the process in a number of plants and animals, and the literature of the subject is now very extensive. In order to express the appearances presented, and the changes which take place both in the nucleus and in the cell in the process of division, a new nomenclature has been introduced, and we now read of cytaster, monaster, dyaster, equatorial plate and crown, pithode or cask-shaped, spindles, ellipsoids, coils, skeins both compact and loose, pole radiations, spirem, and other terms. From the range of the literature it would be a work of considerable labour and time to make an analysis of the different observations so as to associate with the name of each observer the particular set of facts or opinions which he has made known. Fortunately, this is unnecessary on my part, as admirable *résumés* of the whole subject have recently been published both by Prof. McKendrick of Glasgow (Proc. Phil. Soc., vol. xix., Glasgow, 1888) and Prof. Waldeyer of Berlin (*Archiv für Mikros. Anat.*, Bd. xxxii., 1888).

Without entering into a detailed description, it may be sufficient for my present purpose to say that four stages may be recognized in connection with nuclear division.

The *first*, or *spirem stage*, exhibits several phases. At its commencement the finer threads, which connect the primary or coarser chromatin fibres of the resting nucleus together, and which give the network-like character, have disappeared along with the knots at their points of intersection and the nucleoli. The primary chromatin fibres, or *chromosome* as Waldeyer calls them, form a complex coil, the spirem or ball of thread, which divides into loops, about twenty in number, and forms a compact skein. The loops are placed with their apices around a clear space called by Rabl the "polar field," whilst their free ends reach the opposite surface of the nucleus or the "antipole." The nucleus also increases in size contemporaneously. The loops next become not so tightly coiled, and form the loose skein though the individual fibres thicken and shorten. A most important change then occurs, which was discovered by Flemming, and which consists in a longitudinal splitting of each loop or primary chromatin fibre into two daughter threads. A spindle-shaped figure, first seen by Kowalevsky, next appears in the nucleus; it consists of threads that stain much more feebly than the chromatin fibres.[1] The spindle has two poles and an equator, and it finally occupies a position in the deeper part of the nucleus; its equator lies in the plane through which division of the nucleus is about to occur. The loops of chromatin fibres group themselves in a ring-like manner around the equator of the spindle with their angles inwards, whilst from each pole of the spindle a radiated appearance (*cytaster*) extends into the protoplasm of the cell. The membrane of the nucleus has now disappeared, so that it is directly invested by the protoplasm of the cell; and it is possible, as Strasburger thinks, that there may be a direct flow of the protoplasm into the nucleus, and that the spindle may be produced by it. At the pole of the spindle, from the point at which the cytaster radiates, E. van Beneden has seen a small, shining, polar body, which Strasburger says is not found in vegetable cells.

The *second*, or *monaster stage*. When the chromatin loops have arranged themselves about the equatorial plane of the spindle with their limbs pointing outwards, and the angle of the loop towards the centre of the spindle, a single star-like figure (*monaster*, *equatorial plate* or *crown*) is produced. The two daughter threads, into which each primary chromatin thread had previously split longitudinally, now separate from each other, and, according to Van Beneden and Heuser, pass to opposite poles of the nuclear spindle, where they form loops. These changes are known as the process of *metakinesis*.

In the *third*, or *dyaster stage*, the chromatin loops at each pole of the spindle arrange themselves so that the angles of the loops, though not touching each other, are close together at the pole, and the limbs of the loops are bent towards the equator of the spindle. Two stars are thus produced (*dyaster*), one at each pole, and each star is formed of one of the daughter threads into which each chromatin fibre of the monaster divides by its longitudinal splitting. Each star is sometimes called a doughter skein; around each daughter skein a membrane appears at this stage, and a daughter nucleus is then formed.

---

[1] This membrane is perhaps nothing more than a somewhat differentiated layer of the protoplasm of the cell arranged around the nucleus.

[2] The chromatin fibres appear to be composed of granules or spherules, named "microsome-disks" by Strasburger.

[3] Flemming proposed the term *karyomitosis*, or nuclear threads, to express the thread-like figures formed in the process. M. Carnoy gives the name *enchylema* to the apparently structureless material which occupies the interstices of the network in both the nucleus and cell protoplasm.

[1] Owing to the feeble staining of the spindle figure and of the nucleoplasm, the substances which compose them have been named *achromatin*.

In the *fourth* or *dispirem stage*, the chromatin threads thicken and shorten, and the loops of each star arrange themselves with the angles towards the polar field of the nucleus, and the limbs to the antipole.

The division of the mother cell into two new daughter cells is now completed by the cell protoplasm gradually constricting in the equatorial plane until at last it is cleft in twain, and each daughter nucleus is invested by its own mass of protoplasm. The chromatin threads of the daughter skein then form a network of coarser and finer fibres, a nucleolus appears, and the resting nucleus of the daughter cell is completed. Two daughter cells have thus arisen, each of which possesses its own independent vitality. Owing to the very remarkable longitudinal splitting of the fibres of the chromosome, and the distribution of the daughter threads from each fibre to the opposite poles of the spindle, it follows that each daughter nucleus contains about one-half of each chromatin fibre, so that whatever be the properties of the chromosome of the mother cell, they are distributed almost equally between the nuclei of the two daughter cells. As regards the cleavage of the protoplasm, there is no evidence that such a rearrangement of its constituent parts takes place as to give to each daughter cell one-half of the protoplasm from each pole of the mother cell. It is probable that each daughter nucleus simply becomes invested by that portion of protoplasm which lies in proximity to it at the time when the constriction of the protoplasm begins. The young daughter cell, seeing that it is composed both in its nucleus and protoplasm of a portion of each of these constituent parts of the mother cell, possesses therefore properties derived from them both.[1]

Owing to the disappearance of the nuclear membrane at the end of the spirem stage of karyokinesis, at least in cells generally (though it is said to persist in the Protozoa during the whole process of karyokinesis), it follows that the nucleoplasma and the cell protoplasm cease for a time to be separated from each other, and an interchange of material may take place between them in opposite directions—both from the protoplasm to the nucleus, as Strasburger contends, and from the nucleus to the protoplasm, as has in addition been urged by M. Carnoy. In every case it should be remembered that the nucleus, being surrounded by protoplasm, can only obtain its nutrition through the intermediation of that substance, and thus there is always a possibility of the protoplasm acting on the nucleus, and in so far modifying it.

Having now sketched the progress of knowledge of the structure of cells and their mode of production, I may, in the next instance, state the present position of the subject. We have seen that the original conception of a cell was a minute, microscopic box, chamber, bladder, or vesicle, with a definite wall, and with more or less fluid contents. This conception was primarily based upon the study of the structure of vegetable tissue; and, as regards that tissue, it holds good to a large extent to the present day. For the cellulose walls of the cells of plants, with their various modifications in thickness, markings, and chemical composition, constitute the most obvious structures to be seen in the microscopic examination of vegetable tissue. Within these chambers is situated the active, moving protoplasm of the cell, and in it the nucleus is embedded; the cell also contains the sap, crystals, starch granules, or other secondary products. The cell wall is to all appearance produced by a conversion of, or secretion from, the protoplasm. But even in plants a cell wall is not of necessity always present; for, in the development of the daughter cells within a pollen mother cell, there is a stage in which the daughter cell consists only of a nucleated mass of protoplasm, prior to the formation of a cell wall around it by the differentiation of the peripheral part of its protoplasm. Again, the so-called non-cellular plants or Myxomycetes, before they develop their spores,[1] consist of masses of naked protoplasm, on the exterior of which, in the course of time, a membrane of cell wall is differentiated; in the substance of these masses of protoplasm numerous nuclei are situated.[2]

In animal tissues the fat cell possesses a characteristic vesicular form, with a definite cell wall, but neither in it nor in the vegetable cells does the cell wall exercise any influence on the secretion either of cell contents or of matters that are to be excreted. In animal cells a cell wall is frequently either non-existent, or doubtful, and when present is a membrane of extreme thinness. Animal cells, therefore, do not have as a rule the chamber-like form or vesicular character of vegetable cells.

The other constituents of the cell, and the only essential constituents, are the nucleus and the material immediately surrounding it, in which the nucleus is embedded. It is of secondary importance whether this material be called protoplasm, or bioplasm, or germinal matter. The term protoplasm, however, is that which has received most acceptance. In adopting this term, it should be employed in a definite sense to express the translucent, viscid, or slimy material, dimly granular under the lower powers, minutely fibrillated under the highest powers of the microscope, which moves by contracting and expanding, and which possesses a highly complex chemical constitution. The term ought not to embrace either the cell wall of the vegetable or animal cell, or the intercellular substance of the animal tissues. For although these have in all probability been originally derived from the protoplasm, by a chemical and morphological differentiation of its substance, or as a secretion from it, they have assumed formal and special characters and have acquired distinct functions. Protoplasm, as above defined, is a living structure endowed with great functional activity. It possesses a power of assimilation, and can extract from the appropriate pabulum the material that is necessary for nutrition, secretion, and growth. Growth takes place not by mere accretion of particles on the surface, but by an interstitial appropriation of new matter within its most minute organized particles. In cases, also, where the media in which the cell lives are suitable, as in the freely moving Amœba, or the white blood corpuscles, portions of the protoplasm may separate by budding from the general mass of the cell, and assume an independent existence; but the conditions under which the budding off of protoplasm can take place are exceptional in the higher organisms. Protoplasm, therefore, according to this definition, in addition to being a moving contractile substance, is the nutritive and secreting structural element of the tissues, and is always found relatively abundant where growth and the nutritive processes are most active.

In the fertilized ovum, after the process of segmentation has begun, and in the earlier stages of development of the embryo, the cells are nucleated masses of protoplasm, without cell-walls, and with no intercellular material. In the course of time, in animals more especially, an intercellular substance arises apparently by a differentiation of, or secretion from, the protoplasm. In many of the tissues this substance acquires such characters, magnitude, and importance as to overshadow the nucleated masses of protoplasm which it lies between and surrounds. The intercellular substance is the principal representative of the "formed material" of Dr. Beale. I cannot, however, agree with him in regarding it as passive and non-living or dead; for morphological and functional changes take place in it long after its original formation. Thus the hyaline matrix, or intercellular substance, of the young costal cartilages becomes converted into a fibrous matrix in the later period of life, and the striated substance of muscular fibre is one of the most physiologically active tissues in the animal body. In the general economy of the tissues, in the fitting of each to discharge the function for which it is specially intended, the intercellular substance plays an essential part. It gives strength to the bones, toughness and elasticity to ligaments and cartilage, motor power to muscles. It wastes by use and needs repair. But it is probably to the nucleated protoplasm within its substance that we are to look for the structural element which attracts to it the pabulum required for its nutrition, so that the interstitial waste which is consequent on its use may be made good.

---

[1] Dr. J. M. Macfarlane has described as constantly present within the nucleolus of vegetable cells a minute body, which he terms *nucleolo-nucleus* or *endonucleolus*. He considers it, as well as the nucleolus, to become constricted and divided before the nucleus and the cell pass from the resting into the active phase of cell multiplication. See Trans. Bot. Soc. Edin., 1880, vol. xiv., and Trans. Roy. Soc. Edin., 1881–82, vol. xxx.

[1] "Lectures on the Physiology of Plants," by Julius von Sachs; translated by H. Marshall Ward, Oxford, 1887.

[2] The opinion for long entertained that the simpler algæ and fungi and cryptogams generally are destitute of nuclei has been shown by Schmidt and others to be incorrect.

The nucleus is also an active constituent of the cell, and in young cells is proportionately larger than when the cell is matured. It is doubtful if it plays a special part as a centre of attraction in secretion, or in the nutrition of the cell generally, an office which is most probably discharged by the protoplasm; but it undoubtedly acts as a centre for its own nutrition. Numerous observations, moreover, clearly prove the truth of the generalization originally propounded by Martin Barry, and confirmed by Goodsir, that the nucleus is intimately associated with the production of young cells. The karyokinetic phenomena which have been observed during the last fifteen years have established this on a firm basis, beginning with the segmentation of the yelk and nucleus within the fecundated ovum down to the latest period of cell formation.

But, along with the karyokinetic changes within the nucleus and its cleavage, there is also a cleavage of the protoplasm of the cell, so that the daughter cell consists of portions of both the nucleus and the protoplasm of the mother cell. The question therefore has been put whether the division of the protoplasm is a consequence or a coincidence of the division of the nucleus. I am inclined to think that the cleavage of the cell protoplasm is consequent on the nuclear changes; for it must be kept in mind that certain of the movements in and rearrangement of the chromatin fibres of the nucleus precede any rearrangement of particles in the cell protoplasm so far as yet observed, and, still more, the process of cleavage. Applying, therefore, to the cell the well-known economic principle of division of labour, and that differentiation of structure carries with it differentiation of function, I regard the protoplasm as the nutritive and secreting element of the cell, and the nucleus as its primary reproductive factor.

The present position of the cell theory differs therefore in many important respects from the doctrine advocated by Schwann and his immediate successors. Cells are no longer regarded as of necessity bladders or vesicles. A cell wall is not constant but of secondary formation. A free formation of cells within an extracellular blastema by deposition around a nucleolus to form a nucleus, and then around the nucleus to form a cell, does not take place. Young cells arise from a parent cell by division of the nucleus, followed by cleavage of the cell protoplasm, so that each cell is directly descended from a pre-existing cell. Although in so many of its details, therefore, the theory of Schwann has been departed from, yet the great generalization of the cellular structure of plants and animals holds good, and his work will continue to mark an epoch in the progress of biological science.

The study of the very remarkable series of karyokinetic phenomena above described has given an impulse to speculation and thought in connection with some of the most abstruse problems of life and organization. The question of the hereditary transmission of properties, both as regards the constituent tissues of the organism and the individual as a whole, has been put on a more definite physical basis. The penetration of the ovum by the spermatozoon, originally seen by Martin Barry in the rabbit, and extended to other animals some years afterwards by Newport, Bischoff, and Meissner, has been completed by the recent researches of Bütschli, Auerbach, Fol, Hertwig, and E. van Beneden. The conjugation or incorporation of the male pronucleus or head of the spermatozoon with the female pronucleus derived from the germinal vesicle, and the consequent formation of the segmentation nucleus, has been demonstrated. The segmentation nucleus is built up of chromatin fibres and nucleoplasm, derived from both the nucleus of the male sperm cell or the spermatozoon and the nucleus of the female germ cell. It is therefore a composite or hermaphrodite nucleus, and represents both parents. The cells derived from the segmentation nucleus in the early stage of segmentation contain chromatin nuclear particles, which are in direct descent from the chromatin fibres of the segmentation nucleus, and through it from the corresponding fibres of both the sperm and germ cells. From Nussbaum's and E. van Beneden's observations it would seem that each nucleus of the first pair of segmentation cells contains one-half of the chromatin threads of the male, and one-half of those of the female pronucleus. It is possible that an equal division of the male and female components of the nuclei takes place in every subsequent nuclear division, in which case the nucleus of every cell would be hermaphrodite or composite—that is, would represent both parents. The segmentation cells arrange themselves to form the blastoderm, which, in the more complex organisms, by the continuous subdivision of the cells, forms three layers; from which, by a prolonged process of cell division and differentiation, all the tissues and organs of the adult body are ultimately derived. Karyokinetic changes mark the process of cell division throughout, and each daughter cell receives from the mother cell chromatin nuclear material derived from both parents, which, without doubt, conveys properties as well as structure.

In the division of the segmentation nucleus within the ovum a cleavage of the protoplasm of the egg also takes place, and each daughter nucleus is enveloped by the protoplasm of the maternal egg. If during the period of nuclear division there is no interchange of matter between the nucleus and the protoplasm which incloses it, the cell protoplasm would then be derived solely from the ovum, and would represent maternal characters only, whilst the nucleus would possess characters derived from both parents. But if, as is most likely, during the process of karyokinesis, when the nuclear membrane has disappeared, an interchange of matter takes place between the nuclear substance and the cell protoplasm, the latter would then become, if I may say so, inoculated with some at least of the nuclear substance, and be no longer exclusively of maternal origin. Again, it should be stated that, as E. van Beneden has described, when the spermatozoon enters the egg it takes with it a portion of the protoplasm of the sperm cell. This apparently blends with the protoplasm of the egg itself. With Waldeyer, therefore, I would ask the question, Is this altogether without significance? It would seem, therefore, as if the whole of the cells of the body and the tissues derived from them are, as regards both nucleus and cell protoplasm, descended from material originally belonging to both parents.

Although ova in different organisms differ materially from each other in size, shape, the relative amount of food yolk which they contain, the mode of segmentation, and the presence or absence of a segmentation cavity, they all agree in this that the primordial cells of the egg are nucleated masses of protoplasm. Notwithstanding the general resemblance of the morphological units which thus mark the first stage in the production of young organisms, each fertilized ovum gives rise to an organism resembling that in which the egg itself arose. Hence the offspring resemble the parents, and the species is perpetuated by hereditary transmission, so long as individuals remain to keep up the reproductive process. During sexual reproduction the substance of the segmentation nucleus undergoes karyokinetic changes during the act of segmentation, and the question arises if the process of karyokinesis is the same for all organisms, whether plants or animals, or if there are specific differences. As the fertilized ovum is potentially the organism which is to arise from it, specific differences not unlikely exist in the minute structure of the segmentation nucleus, which may perhaps be expressed by modifications in the arrangement of the chromatin fibres and in the number of their loops. The varieties which have been described in the forms of the karyokinetic figures and polar radiations in different plants and animals may perhaps mark these specific differences.

But there is another question which merits consideration. Are the karyokinetic phenomena which show themselves in the cells of a given tissue characteristic of that tissue? and, if so, would it be possible to distinguish one tissue from another in the same organism by differences in the process of cell division? On this point a commencement seems to have been made towards obtaining some positive knowledge. Strasburger and Heuser think that they have obtained evidence in certain plant cells that such is the case; Rabl concludes, from observations on the epidermic cells of salamander, that the loops of chromatin fibres are constantly twenty-four in number in the same kind of cell in the same species of animal.

But in considering the different kinds of tissue, and the possibility of each kind possessing its characteristic karyokinetic process, it has to be kept in mind that more than one kind of tissue, each of which has its characteristic structure and function, arises from each layer of the blastoderm, so that there is a stage in development—a stage of indifferentism, if I may use the expression—when the blastoderm represents several tissues which have not yet differentiated. From the epiblast, for example, tissues so diverse in structure and function as cuticle and nerve tissue arise. Now, if there be a special karyokinetic process for the epidermal cells, and another for the nerve cells, does either of these correspond with the process of nuclear division in the cells of the epiblast in their stage of indifferentism, or do they both differ from it? When does the impulse reach the layers of the blastoderm, so as to produce in their constituent cells changes which so alter the characters of the cells as to lead to a differentiation into various forms of tissues, and to what is that impulse due? In the development of each species there seems to be a definite time within certain limits when the differentiation shall begin, and when the process of development of the tissues and organs shall be completed. This is an hereditary property, and is transmitted from parents to offspring. Is the impulse derived from the nucleus or from the cell protoplasm, or do both participate? As already stated, the nucleus is the element which is immediately descended from both parents, and which may therefore be supposed to be the primary morphological unit through which hereditary qualities are transmitted. But, as is most probable, the nucleus reacts on the cell protoplasm—on the element of the cell through which the ordinary nutritive functions are discharged. As a consequence of this reaction, when the appropriate time arrives in the development of each species for the commencement of the differentiation of the protoplasm of a cell, or group of cells, into a particular kind of tissue, the necessary morphological, chemical, and physiological changes take place. When once the differentiation has been effected, it is continued in the same tissue throughout the life of the organism, unless, through some disturbance in nutrition, the tissue atrophies or degenerates. Every multicellular organism, in which definite tissues and organs are to arise in the course of development, has therefore a period, varying in its duration in different species, in which certain of the properties of the cells are as it were dormant. But, under the influence of the potent factor of heredity, they are ready to assume activity as soon as the proper time arrives. When the process of differentiation and development is at an end, the organism has attained both its complete individuality as regards other organisms, and its specific characters.

Every organism, therefore, has to be viewed from both these points of view. Its specific position is determined by that of its parents, and is due to the hereditary transmission of specific characters through the segmentation nucleus. Its individuality is that which is characteristic of itself, and arises from the fact that in the course of development a measure of variability within the limits of a common species, from the organic form exhibited by its parents and by their other offspring, is permitted. In all likelihood the variability, as Weismann suggested,[1] is, to a large extent, occasioned by the bisexual mode of origin of so many organisms. By the expulsion of the polar bodies, during the maturation of the egg, portions of the ancestral germ plasm may be removed, and as corresponding molecules need not be expelled from each ovum, similar ancestral plasms would not be retained in each case, so that diversities would arise. There is also a possibility of the molecular particles of the segmentation nucleus and of the nuclei of the cells descended from it, having a method of arrangement and adjustment, and a molecular constitution characteristic of the individual as well as of the species. On this matter we have, however, no information. It is as yet a mere hypothesis. When we consider the extreme minuteness of the objects referred to, and recollect that it is only about fifteen years since karyokinetic phenomena were first recognized, it is astonishing what progress in knowledge has been made within this limited period. We owe this great advance to the much more complete magnifying and defining power of our microscopes, to the improved method of preparation of the objects, and to the acute vision and clear-thinking brains of those observers who have worked at the subject. By continuing the work, and extending it over a wider area, we may hope in time to be able to solve many questions to which we cannot now give an answer.

The nuclear material which makes up the substance of the male and female pronuclei, by the fusion of which the segmentation nucleus is formed, has been termed by Prof. Weismann the *germ plasm*. In a series of elaborate papers he has developed a theory of heredity,[2] based upon the supposed continuity of the germ plasm. He believes that in each individual produced by sexual generation a portion of the germ plasm derived from both parents is not employed in the construction of the cells and tissues of the soma, or personal structure of that individual, but is set aside unchanged for the formation of the germ cells of the succeeding generation—that is, for reproduction and the perpetuation of the species.

---

[1] See his essays, "The Significance of Sexual Reproduction in the Theory of Natural Selection," and "On the Number of Polar Bodies and their Significance in Heredity," translated in "Essays on Heredity" (Oxford, 1889).

[2] Translations of these papers have been published by the Clarendon Press, Oxford, 1889.

According to this theory, the germ plasm, more especially through the chromatin fibres, is the conveyer of hereditary structure and properties from generation to generation. Further, he holds that the cells, tissues, and organs, which make up the somatic or personal structure of the individual, exercise no modifying influence on the germ or reproductive cells situated in the body of that individual, which cells are also, he thinks, unaffected by the conditions, habits, and mode of life. In its fundamental idea Weismann's theory is in harmony with one propounded a few years earlier by Mr. Francis Galton (Proc. Roy. Soc. London, 1872; and Journ. Anthrop. Inst., vol. v., 1876).

In an address delivered at Newcastle in September last to the Anthropological Section of the British Association (NATURE, September 26, 1889), I reviewed this theory of heredity, and, whilst finding in it much with which one could coincide, I directed attention to points to which, I thought, objection might be taken. More especially I took exception to the idea that the germ plasm was so isolated from the cells of the body generally as to be uninfluenced by them, and to be unaffected by its surroundings.

On this occasion I propose to say a few words on the bearing of this theory on the development of the tissues and organs of the individual. If we examine the development of the embryo, say of one of the Vertebrata, we find that it makes a certain advance, varying in its time and extent according to the species, without any differentiation of a reproductive organ with its contained germ plasm being discoverable. I shall not enter into the much-disputed question of the layer or layers of the blastoderm from which the reproductive cells take their rise. But I may say that in the chick, both in the third and fourth day of incubation, a layer of germinal epithelium may be seen in close relation to the Wolffian duct and the pleuro-peritoneal cavity. At the end of the fourth day or in the fifth day this epithelium becomes thickened, and the primordial ova appear in it as distinctly differentiated cells. In the rabbit a corresponding differentiation does not appear to take place before the twelfth or thirteenth day. Up to the period of differentiation of the primordial ova, no isolation or separation of the reproductive cells and germ plasm has taken place; and, so far as observation teaches, there is nothing to enable one to say which cells of the blastoderm may give rise to primordial ova, or which may differentiate into cells for other histogenetic purposes. But before the germ cells appear, the rudiments of the nervous, vascular, skeletal, muscular, tegumentary, and alimentary systems, and the Wolffian bodies or primordial kidneys have all been mapped out. Up to this time, therefore, in all probability, a more or less complete diffusion of the germ plasm throughout either one or more of the layers of the blastoderm has taken place. The hereditary influence conveyed by the germ plasm would thus be brought to bear upon the cells of the blastoderm generally, so as to impart to them the power of undergoing at the appropriate period the morphological and chemical differentiation to form the several tissues. As the tissues and organs are derived through division of the nuclei from the cells of the blastoderm, the continuity of the hereditary influence exercised over them is kept up, even after the germ plasm has become isolated, and the entire organism is moulded so that it acquires its specific and individual characters.[1]

But the diffusion of the germ plasm throughout either the whole of the blastoderm, or a part thereof, of necessity so intimately associates it with the formative cells of the tissues generally, that it is difficult, if not impossible, to comprehend how in its turn it can be unaffected by them. Before, therefore, it again becomes stored up or isolated in an individual, in the form of ova or sperm cells, it has in its stage of diffusion been brought under precisely the same influences as those which in the embryo affect the formative cells of the whole body.

From the observations and reasoning of Wilhelm His (Proc. Roy. Soc. Edin., April 2, 1888), there can, I think, be no question that the layers of the blastoderm are affected by pressures and other mechanical conditions. These pressures would produce or modify flexures, or occasion a diminution in dimensions in some directions and an increase in others; and in this way would tend to affect either the form of the entire organism, or the form and relations of its constituent parts, or perhaps both. Should such modifying influences come into operation either before the isolation of the germ plasm, or when it was in a plastic or impressionable condition, one could conceive that it might be affected by them. Molecular changes might thus be induced in the germ plasm of such a kind as to modify the properties of the chromatin constituent of the nuclei, so as to induce in it and the germ plasms descended from it corresponding modifications, which would become hereditary. If such an hypothesis be granted, it would follow that the external conditions would exercise a perceptible influence on the germ plasm of the reproductive cells, both in the individual in which they first manifested their effect and in the generations which are descended from him.

If the germ plasm, from the first stage of development of each organism, were completely isolated from the cells from which all the other cells of the body were produced, it would be possible to conceive its transmission from generation to generation unaffected by its surroundings. But as in each individual a stage of diffusion or non-isolation precedes that of differentiation into the special reproductive apparatus, it follows that the conditions which would secure the germ plasm and the soma cells from mutual interaction are not complied with. On this ground, therefore, as well as for the reasons previously advanced in my Newcastle address on heredity, I am unable to accept the proposition that there can be no transmission to the offspring, through the reaction of the soma on the germ plasm, of characters which may be acquired under direct external influences. But in questioning the accuracy of the proposition that somatogenic "acquired characters" are incapable of being transmitted, I do not of course contend that all the characters which may be acquired during the lifetime of an individual are perpetuated in his descendants.

THE LABORATORY OF VEGETABLE BIOLOGY AT FONTAINEBLEAU.

THIS Laboratory, the establishment of which we have already announced, has now been in full working order, as far as the present buildings will permit, since May 15. We are enabled to furnish our readers with the following account of its scope and design, with the accompanying sketches, from an article supplied by M. Jumelle to the *Révue Générale de Botanique*.

The Laboratory was established at the suggestion of M. Liard, the Director of Higher Instruction in France, and

---

[1] On the question of the influence exercised by the germ plasm on the tissues, I may refer to some most suggestive remarks by Sir James Paget, published forty years ago, in the *London Medical Gazette*, 1849, in one of his lectures (VI.) on "The Processes of Repair and Reproduction after Injuries:"—"In every impregnated germ we must admit that properties are implanted which, in favourable conditions, issue in the power to form, of the germ and the materials it appropriates, a being like those from which it sprang. And, mysterious as it may seem, yet must we conclude that a measure of those properties is communicated to all the organic materials that come within the influence of the germ; so that they, being previously indifferent, form themselves in accordance with the same specific law as that to which the original materials of the germ are subject. So through every period of life the same properties transmitted and diffused through the whole organism are manifested in the determination of its growth and maintenance, in its natural degeneration, and its repair of every part, in accordance with that type or law which has prevailed in every individual of the species." See also a lecture "On the Formative Process," in "Lectures on Surgical Pathology," vol. i., London, 1853.